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E.P. NOTE 18

Tritium Concentration Reduction Factors for MI30, MI40, MI52 and MI62 locations

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Introduction

The concentration Model (Co99) is the methodology used at Fermilab to predict the production and subsequent migration of radionuclides in the soil around the beam targetting or loss areas. The predictions of this model are used in the design of new facilities and the operation of the existing facility to keep the concentration of the radionuclides in the surface waters and the ground water below the prescribed and regulatory limits (see reference GWR).

This note describes a calculation of the transport of the radionuclides, produced in the soil, to the groundwater, for the major loss points (injection, extraction points and the beam absorber) of the Fermilab Main Injector.

A Brief Description of the Concentration Model

The concentration model uses the star density produced in the soil. This is usually obtained from a standard Monte Carlo code that simulates beam loss and the subsequent production of radionuclides in the soil in the vicinity of the enclosures. Star density, number of protons lost, the radionuclide yield, half life and leaching parameters, in conjunction with some soil parameters, are used to calculate the concentration of the radionuclides, C_i, right outside the enclosure. This concentration can be directly compared with the allowed concentration values for discharge to the surface waters.

The next step in the concentration model calculation is the transport of this initial concentration from the production level, immediately outside the enclosure walls, to the aquifer. The radionuclide plume moving through the soil will decay and expand, therefore, reducing its concentration. This reduction is taken into account through the calculation of a reduction factor R. Thus the final concentration of the radionuclides, C_f, in the aquifer will be;

$C_f = C_i * R.$

The radionuclide plume moves through the glacial till, the glacial till-dolomite interface, and within the dolomite, in its transport to a well. IEPA standards imply that, one should assume no reduction factors due to migration through the till-dolomite interface and transport in the dolomite - both regions designated as Class I groundwater resources. Therefore, the reduction factor R, used in the calculation is only due to the transport through the glacial till.

Originally, the reduction factor was calculated based on one site-wide average vertical seepage velocity (Ma93, Co94). Further experience and investigation of the loss points at different locations at the lab showed that the use of one site-wide average velocity is neither correct nor conservative. The latest version of the concentration model recommends the use of site specific geological characterizations as input to transport calculations using the computer code PATCH3D (Co99).

Groundwater Transport Code PATCH3D

PATCH3D is a computer program that analytically solves a three dimensional advection-dispersion equation for the vertical transport of radionuclides in the soil (Su88). The calculations for the Main Injector presented below were done by transporting a 3.7m by 3.7m rectangular patch containing the initial radionuclide concentration in a direction perpendicular to the patch, downward to the aquifer. This code requires values for the vertical seepage velocity within the layer, the decay constant of the radionuclide, the thickness of the layer, and longitudinal and transverse dispersivities. The dispersivities were determined empirically as described in the reference Co99.

The vertical seepage velocity is calculated from the hydrogeological properties - gradient, hydraulic conductivity and effective porosity (given as I, k and n on the figures) - of the layer through which the transport is calculated. For the cases where there are several intervening layers between the radionuclide production point and the aquifer, the calculations here were done for the total distance between the production point and the aquifer using one average velocity. The migration of the radionuclide through each layer is dependent on the thickness and vertical seepage velocity for that layer. Therefore, a weighted average (the so-called Harmonic Average) velocity was calculated, based on transit times as weights (WCC93).

The hydrogeological input parameters for the Main Injector major loss regions MI30, MI40, MI52 and MI62 are based on the information obtained from geological characterizations of the soil samples from boreholes S-1249, S-1250, S-1251, S-1255, S1256 and S-1257 (Figs. 1 - 5), near the MI loss regions.

Results

Measurements and calculations (Bo72 and Ma93) have shown that, of all the radionuclides produced in the soil, ^{3}H and ^{22}Na are the most significant due to their yields, half lives, transportability in the soil, leachability from the soil, and the allowed concentrations in the groundwater. In usual cases at Fermilab, where the enclosure is located in the till, tritium is the main contributor to ground water contamination. ^{22}Na, due to its smaller production cross section, half-life and distribution coefficient (Bo72) has a much larger reduction factor. Therefore, the following calculations were only done for the transport of tritium.

The calculations were done for five-year, ten-year, fifteen-year and twenty-year continuous accelerator operation periods. Using the latest geological parameters for the MI loss points, the calculations indicate that it will take anywhere from 125 to 240 years for the maximum tritium activity produced to get to the aquifer. It is this maximum activity on which the reduction factors shown here are based.

MI62

There are 60 cm of Henry formation and 7 m of Lemont Formation under the MI62 enclosure. Using the information given on the geological plot (Figure 2), a seepage velocity of 0.55 cm/yr was calculated for the Lemont formation. The calculations were done only for the Lemont layer. Two sets of reduction factors were calculated, depending on what thickness of soil around the enclosure was used to calculate the average star density from the maximum star density. If in the calculation of C_i (initial tritium concentration), S_{ave} represents an average over a 60 cm thick soil layer around the enclosure, the reduction factors for 7 m should be used. If the average is over a 160 cm thick volume, the reduction factors for 6 m should be used. The results are given in Table 1 below.

Table 1. MI62 reduction factors for different periods of operation.

MI-62 (Years of Operation)	Reduction Factor (for 6 m)	Reduction Factor (for 7 m)
5	2.6E-10	1.01E-11
10	5.2E-10	2.E-11
15	7.8E-10	2.99E-11
20	1.03E-9	3.95E-11

MI52

There are three soil layers (Fig.3), about 11.6 m thick, under the MI52 location. The average vertical seepage velocity for the combined layers is 1.09 cm/year. The reduction factors for the migration through 11.6 meters of soil, given in Table 2 below, are to be used when maximum star density is used in the calculation of the initial radionuclide concentration. If the initial tritium concentration is calculated using a star density averaged over 1.6 m of soil around the loss point, then the reduction factors due to the transport through 10 m of soil should be used.

Table 2. MI52 reduction factors for different periods of operation.

MI-52 (Years of Operation)	Reduction Factor (for 10 m)	Reduction Factor

		(for 11.6 m)
5	1.7E-9	1.13E-10
10	3.3E-9	2.26E-10
15	4.9E-9	3.33E-10
20	6.5E-9	4.39E-10

MI40

There are 45 cm of Lemont formation facies B and 410 cm of Lemont formation facies C under the MI40 enclosure. Using the geological information given in Fig.4, a seepage velocity of 0.65 cm/yr was calculated for the facies C. The transport calculations were done only for the main layer, facies C. In the calculation of the initial concentration, S_{ave} must be used as prescribed in the revised concentration model EP-17. However, for the calculation of the contamination of the groundwater, since the 45 cm facies B was not included in the reduction factor calculation, instead of S_{max}, a star density averaged over 45 cm of soil may be used. The results for 4.1 m transport distance is shown in Table3.

Table 3. MI40 reduction factors for different periods of operation.

MI-40 (Years of Operation)	Reduction Factor (for 4.1 m)
5	2.9E-8
10	1.35E-8
15	8.5E-8
20	1.15E-7

MI30

There are three soil layers under MI30, as shown in Figure 4, with a total thickness of 7.8 m. The average seepage velocity for the combined layers is 0.99 cm/year. The reduction factors for use with the maximum (7.8 m) or average (6 m) star densities are given are given in Table 4.

Table 4. MI62 reduction factors for different periods of operation.

MI-30 (Years of Operation)	Reduction Factor (for 6 m)	Reduction Factor (for 7.8 m)
5	1.72E-7	3.2E-9
10	3.42E-7	6.3E-9
15	5.12E-7	9.4E-9
20	6.72E-7	1.25E-8

Closing Thoughts

A comparison of the above reduction factors with that calculated using a standard parameterization for the whole site (Ma93) shows that the present results are smaller by several orders of magnitude. The main reason for this difference is that the standard model assumes 15 cm/year vertical seepage velocity. None of the cases studied above have such a large vertical seepage velocity. Since, the velocity folds in exponentially, the difference in reduction factors becomes large. As mentioned above the reduction factors for the transport of ^{22}Na are much larger than for tritium for the cases calculated above. However, when the tritium concentrations become comparable to the ground water limit, factors for sodium should be explicitly calculated and included in the final concentrations. In cases where there are multiple layers, there are actually two methods of calculating the transport of the tritium. The first method is to calculate the reduction factor for each layer with the final reduction factor a product of all of the individual ones. The second method is to use the harmonic average velocity for all the layers, as described above. This is a fast method of calculation since it involves the total depth and one average velocity, and is the method used in this paper. However, in the case of one intervening slow layer, the final concentration may be dominated by this layer, and one may need to consider the lateral spread of the patch size, to which the "fast method" of using an average velocity will not be sensitive.

References

Bo72 T. B. Borak, M. Awschalom, W. Fairman, F. Iwami, and J. Sedlet, "The Underground Migration of Radionuclides Produced in Soil Near High Energy Proton Accelerators." Health Physics 23, 679-687 (1972).

Co99 Cossairt, J. D., A. J. Elwyn, P. Kesich, A. Malensek, N. Mokhov, and A. Wehmann " The Concentration Model Revisited", E.P. Note #17. June 1999.

Co94 Cossairt, J. Donald "Use of a Concentration-Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab" E.P. Note #8. December 1994.

GRW Ground Water Regulations;
DOE Orders and Guidance (DOE5400.5)
U.S. EPA Regulations (40CFR141)
Illinois EPA Regulations (35 IAC 620)

Ma93 Malensek A. J., A. A. Wehmann, A. J. Elwyn, K. J. Moss, and P. M. Kesich, "Groundwater Migration of Radionuclides at Fermilab", Fermilab Report TM-1851, August 1993.

Su88 E. A. Sudicky, T. D. Wadsworth, J. B. Kool, and P. S. Huyakorn, PATCH3D-Three-Dimensional Analytic Solution for Transport in a Finite Thickness Aquifer with First-Type Rectangular Patch Source. Prepared for Woodward Clyde Consultants, HydroGeologic Inc. Herndon, Va., January 1988.

WCC93 Woodward-Clyde Consultants, Summary of Radionuclide Transport Modeling for Ground Water at the Fermi National Accelerator Laboratory, Batavia, Il., Project 92C3073, Chicago, Il., August 1993.

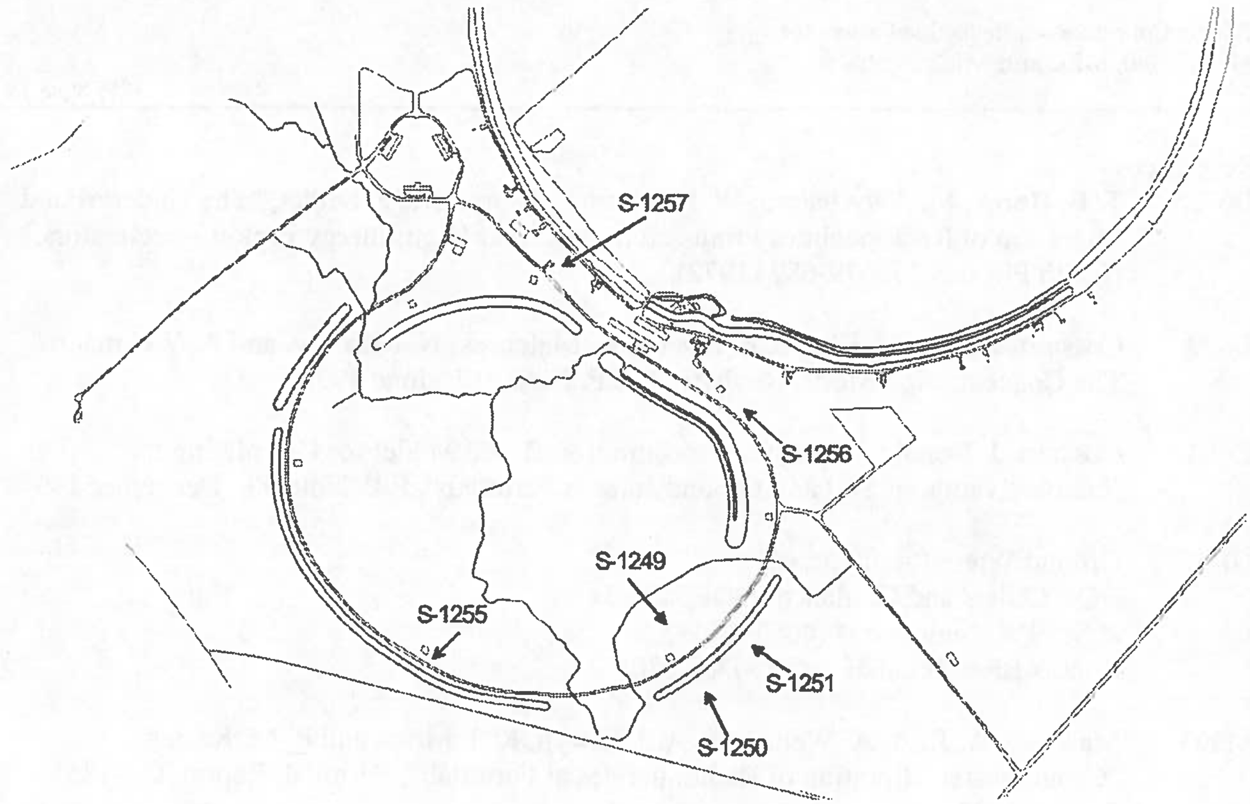


Fig. 1: Location of the boring sites around the Main Injector.

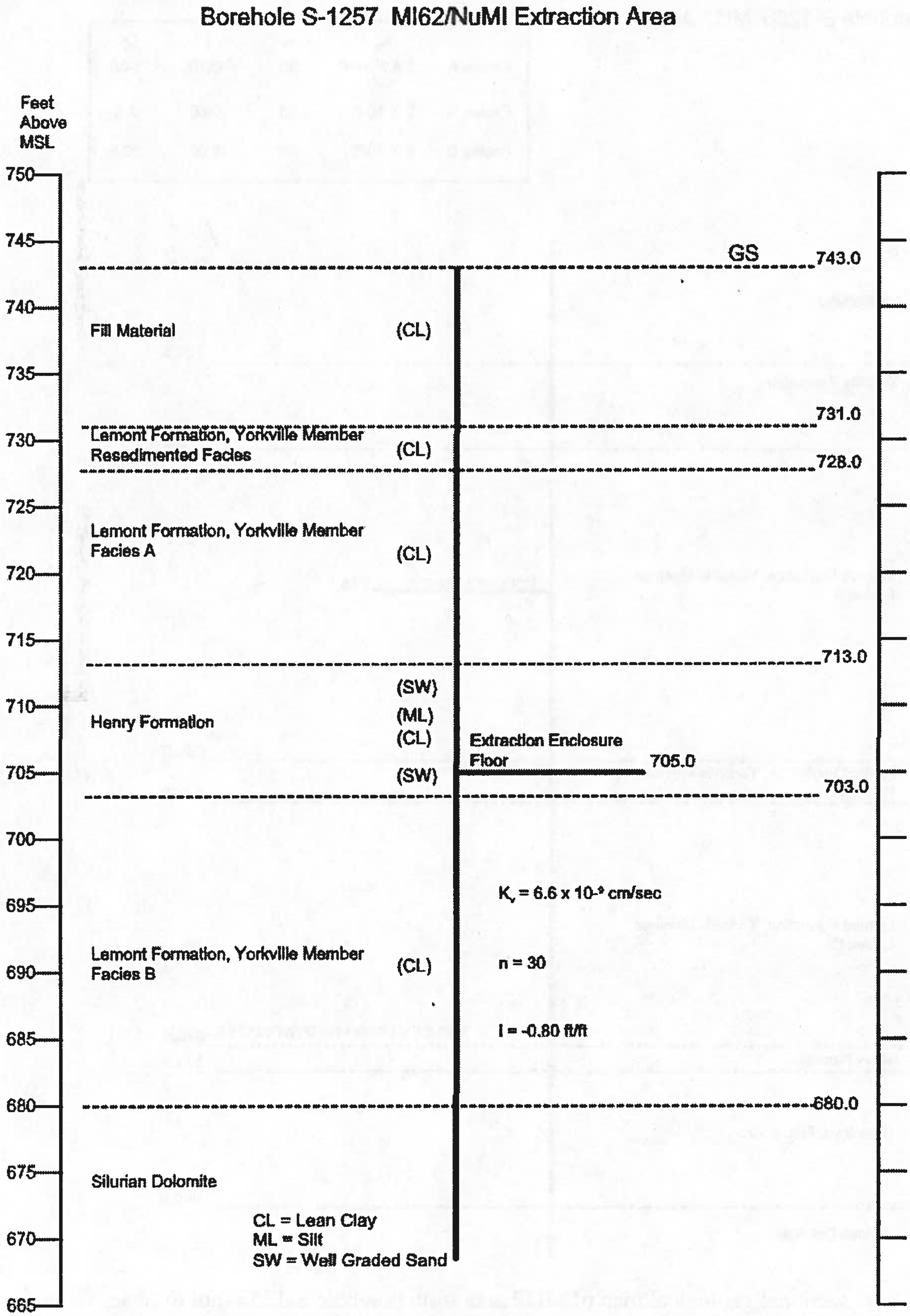


Fig. 2: Cross sectional geological map of MI62 area from borehole S-1257 (not to scale)

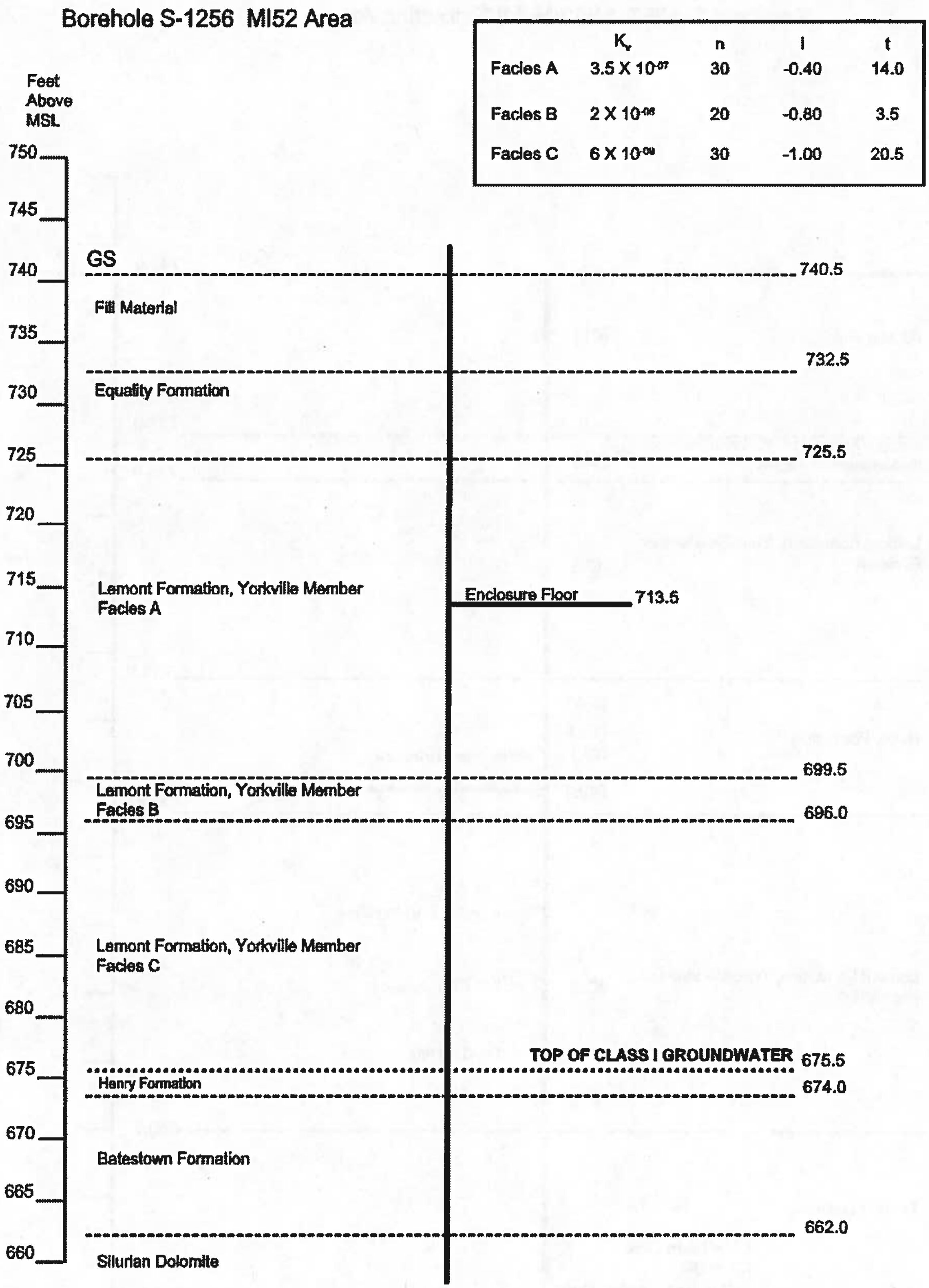
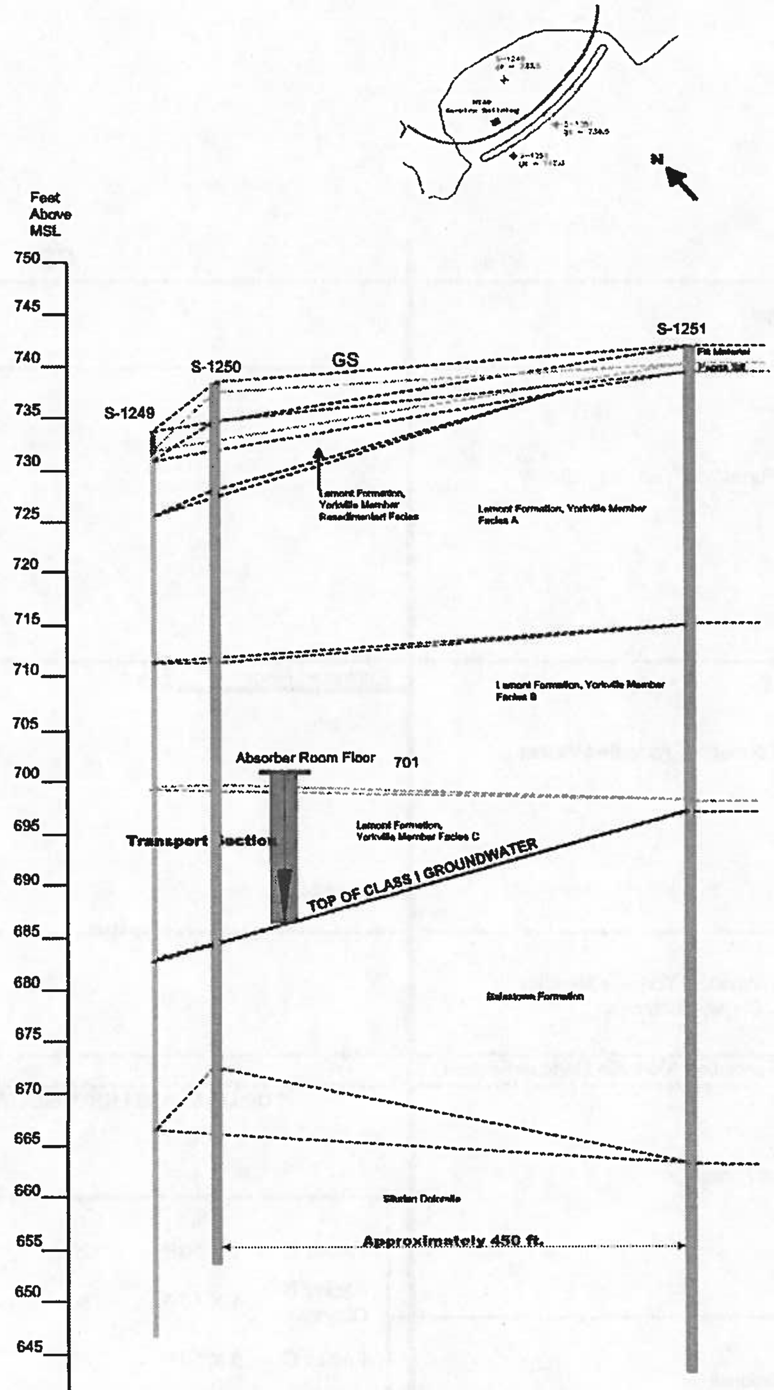


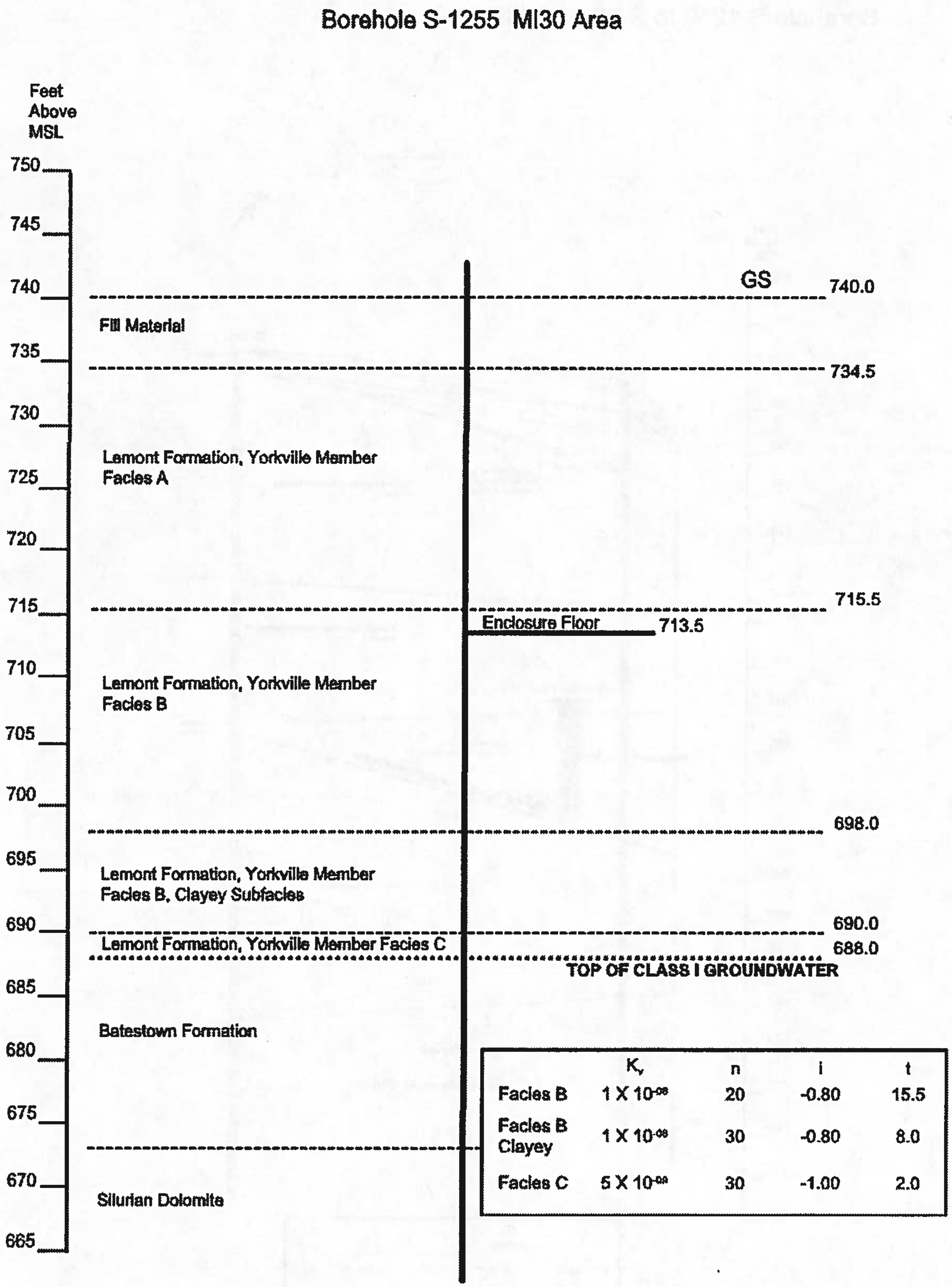
Fig. 3: Cross sectional geological map of MI52 area from borehole S-1256 (not to scale)

Borehole S-1249 to S-1250 MI40 Area



	K, cm/sec	n	i	t cm
Facies B	2.1 X 10[illegible]	0.20	-0.80	45
Facies C	6.2 X 10[illegible]	0.30	-1.00	410

Figure 4: Cross sectional geological map of MI40 area from boreholes S-1249, S-1250 and S-1251 (not to scale)



	K_v	n	i	t
Facies B	1×10^{-08}	20	-0.80	15.5
Facies B Clayey	1×10^{-08}	30	-0.80	8.0
Facies C	5×10^{-08}	30	-1.00	2.0

Figure 5: Cross sectional geological map of MI30 area from borehole S-1255 (not to scale)